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Variation in the Mechanical Properties of Reinforcing Bars

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VARIATION IN THE MECHANICAL PROPERTIES OF REINFORCING BARS

BY

JAMES MARION WHELAN, JR.

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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May 31, 1913

This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by JAMES MARION WHELAN, JR., entitled Variation in the Mechanical Properties of Reinforcing Bars is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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Instructor in Charge.

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VARIATION IN THE MECHANICAL PROPERTIES OF REINFORCING BARS.

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VARIATION IN THE MECHANICAL PROPERTIES OF REINFORCING BARS.

I. INTRODUCTION.

The phenomenal development of reinforced concrete in the last few years has brought with it new materials, new methods, new structures, and consequently, many new problems. So rapid has been the advance in the use of concrete, that the proper working out of many of these problems has lagged far behind the need of their solution. Even the materials themselves have not been thoroughly standardized. It is true that the cement, sand, and stone, and the resulting concrete have been the subjects of much study and discussion and many questions concerning them have been settled. The quality of the steel reinforcement, however, has, until the last year or two, been neglected.

The material used for the first reinforcing bars was the mild steel or low-carbon grade known as structural steel. This was natural as structural shapes were frequently used as reinforcement. Also, the properties of this mild steel were well known, and the mills were making it in large quantities, so that it was easy to obtain. It was early seen, however, that the maximum effective strength of the reinforcement depended upon the yield point of the material.

The desirability of a high elastic limit led to the use of high-carbon steel. The cheapness of scrap railroad rails led to their use as a raw material in place of new high-carbon billets. The treatment of these scrap rails is simple. They are first heated and split from end to end so as to form three

separate pieces, the head, the web, and the flange. Bolt-hole ends of the web are then cut off and each of the three parts of the rail passed thru rolls and formed into bars. The raw material is cheap and the process of manufacture is simple and requires no great plant, consequently the product can be sold at a price as low or lower than the mild, low elastic limit material.

It has been claimed by many that the old rails used were not at all uniform in quality and had a high sulphur and phosphorus content, making the bars brittle and liable to breakage when bent either hot or cold. Besides, it has been said that bars rolled from bundles of miscellaneous scrap rods or other old material have been put on the market. Many conservative designers refused to use the rerolled material. The specifications for reinforcing steel adopted in 1911 by the American Society for Testing Materials required all bars to be rolled from new billets. The adoption of this specification was protested by the Rail Steel Bar Manufacturers Association, and in March, 1912, the American Society for Testing Materials passed a resolution stating that the specification adopted was intended merely to give the requirements for new billet material and not to prejudice anyone against rerolled bars. Other well known societies have begun, in the last few years, to take an interest in the properties of various kinds of reinforcing bars. One of the first to change their requirements so as to allow rerolled rail steel to be used was the National Association of Cement Users in 1910. In June, 1912, the Association of American Steel Manufacturers adopted a separate specification for rail

steel bars, leaving the question of the kind of bars to be used an open one to be settled by each individual purchaser.

It is evident that the variation in the mechanical properties of reinforcing bars due to differences in the material used is a very important problem, and, since it has been studied but little, it offers a new and extensive field for investigation. It is the purpose of this thesis to study the variations in yield point, ultimate strength, and elongation found in the ordinary tension tests of three kinds of reinforcing material,- new billet mild steel, new billet high-carbon steel, and re-rolled rail steel.

II. QUALITIES NEEDED IN REINFORCING BARS.

In discussing the relative merits of different materials and the importance to be given to the variations in any one property, the following general requirements for a good reinforcing steel should be kept in mind.

1. It should be strong in tension, that is, should have a high yield point. Except in columns, the steel is so placed that it is under direct tensile stress. The tensile strength should be considered as the yield point rather than the ultimate strength, for, as soon as the stress in the steel in a beam passes the yield point and the bars begin to deform more rapidly than the concrete on the compressive side, the neutral axis, or plane of no deformation rises, and excessive stresses are thrown into the concrete, resulting in the failure of the beam.

2. It should be sufficiently tough and ductile that the bars may be bent into the forms required without injury to the metal. It should have sufficient toughness to resist the effect of impact, but the impact effect upon steel used as reinforcement in a concrete structure is much less than in all-steel construction on account of the greater dead weight and the monolithic construction.

3. It should be uniform in quality. Uniformity or reliability in a material is a prime requisite for begetting the confidence of the consumer and is very necessary to the economical use of that material. Steel that is uniform can be worked on a basis of its average strength; while, in bars having a wide variation in properties, the working loads must be based on the weakest specimens, reducing all to a common low level and losing much of the advantage of the high average strength.

No one material can possess all the desired qualities in the highest degree. The tensile strength may be increased by increasing the percentage of carbon, but this reduces the ductility. Plate 1, taken from H. H. Campbell's "Iron and Steel", shows that an increase of .01% in the carbon produces an increase in the ultimate tensile strength of about 800 lb. per sq, in. for the basic steel and 1000 lb. per sq. in. for acid steel. The effect on the yield point is greater since the ratio between the yield point and the ultimate strength increases as the ultimate strength is increased. The decrease

in ductility is indicated by the decrease in elongation as the ultimate strength increases.

In general, steel reinforcement may be divided, as to tensile strength, into two classes,- low-carbon steel or the structural grade, and high-carbon or hard steel. The amounts of carbon used are such that the hard steel has a yield point of about one and one-half times that of the low-carbon grade, standard specifications requiring a minimum of 50,000 lb. per sq. in. for the high-carbon and 33,000 lb. per sq. in. for the low-carbon steel. If the other necessary qualities of ductility and uniformity were equal, the working stresses in the hard steel could be one and one-half times those in the structural grade, provided no other limitations were put upon the working stress; only two-thirds as much steel would be required and the softer metal would practically go out of use, not only in reinforced concrete, but also in steel building and bridge work.

That this is not the case has been due largely to the change in ductility and resistance to shock that results from an increase in the carbon content. As the hardness and strength increase, the ductility decreases, the steel becoming more brittle and less able to resist impact. It has been assumed that the relation between ultimate strength and elongation, which is the most convenient measure of ductility, could be expressed by the simple formula; Elongation (in per cent)$= \frac{k}{S}$, k being a constant and S the ultimate strength in lb. per sq. in. That this does not hold over a wide range of ultimate strengths is

shown by the fact that in all standard specifications, the k used for mild steel differs from that used for the hard grade, the usual range being from 1,400,000 to 1,000,000.

It is easily seen why mild steel only should be used in steel buildings and bridges where the impact is great and where each piece of steel acts as a unit so that the failure of any one piece might result in the wrecking of the whole structure. In reinforced concrete construction, however, a different state of affairs exists, and it is probable that the importance of ductility and high elongation in reinforcing bars has been overestimated. The shock received by the reinforcement is very slight compared to the impact in a hanger or a floor-beam of a railroad bridge. The concrete structure is massive, and usually monolithic; there are no pin connections or loose joints in which vibrations may be set up; and the shock is probably largely absorbed by the concrete.

The ductility required depends, then, not so much on the need for resisting shock as on the amount of bending that must be done in fabricating the reinforcement. Each bend is, in a measure, a test. The very brittle bars crack or show other signs of weakness and are discarded; the others, even tho they be injured slightly, are strong enuf to carry the low stresses that are found at the points where the rods are bent up. The ductility required in the fabrication of reinforced concrete structures is much less than that found necessary with the various punching, drifting, riveting, bending, and shearing pro-

cesses involved in the fabrication and erection of structures composed of structural shapes.

The great use of mild steel despite its low strength must beattributed then, not to its unnecessarily high ductility, but to the lack of confidence in the uniformity of high-carbon steel. The hard steel is more liable to injury in manufacture and requires more careful handling than the structural grade. The lack of knowledge of the uniformity of rail steel and the fact that so many different kinds of scrap rails may be used in its manufacture has made engineers particularly cautious about accepting that material.

III. EXPERIMENTAL DATA AND DISCUSSION.

To secure data on the uniformity of the steels, the writer made some 240 tension tests of various sizes of low-carbon and rail steel plain bars. He also obtained data of nearly 200 tests made by the Engineering Experiment Station in 1909. These data are given in Tables II to IX. The results have been plotted as uniformity curves and are given in Plates 8 to 9. The Plates give for each size and variety of bar the mean yield point, ultimate strength, and elongation in eight inches. The Plates show the proportional number of tests which lie between the mean value and any specified variation from the mean. This proportion is given in terms of the percentage of the total number of tests. To illustrate, in making

Plate 3, the mean yield point for the 88 bars tested was 40,420 lb. per sq. in. 102% of this is 41,230 lb. per sq. in. 42 tests, or 47.7% of the whole 88, had a yield point between 40,420 and 41,230 lb. per sq. in. One point on the curve was then plotted with 102% of the mean as an ordinate and 47.7% of the total number of tests as an abscissa. Several standard requirements, for example, a minimun yield point of 33,000 lb. per sq. in., have been plotted in terms of the mean as horizontal lines, so that the proportion of test fufilling the standard specifications may be readily seen. Plates 2 to 6 are for low-carbon bars, the sizes tested being 3/8, 1/2, 5/8, 3/4, and 1 inch. Plate 7 is for 3/4 in. high-carbon new billet steel and Plates 8 and 9 are for high-carbon rail steel of two sizes, 1/2 and 1 in.

Each set of bars tested by the writer was from a single shipment and would be expected to be more uniform than bars bought at different times and in different markets. Plates 2 and 6, plotted from the writer's tests, show a great deal less variation than Plates 3, 4, and 5 from bars taken from many different shipments in 1909. From 3 to 8 of the writer's test pieces were from a single bar and, altho this should not affect the curves materially, the extent of the tests is narrower than if but one test piece had been cut from each bar and the same number of tests made. For these reasons, the 1909 tests should be given greater weight than the 1913 tests of mild steel bars.

One of the first things to be noted in the plates is

that the yield point curve is usually on the inside and the elongation curve on the outside, showing that the yield point, which is the most important property, is the most uniform, and the elongation the most variable of the three properties. The three curves lie fairly close together,showing that the three properties of yield point, ultimate strength, and elongation, are related, a given variation in one property being found with coresponding variations in the other two. An apparent exception occurs in Plate 4, where the elongation curve takes a long downward sweep. This is unimportant,as it was caused by but one brittle bar; the small number of tests accounting for the large effect of one bar on the curve.

The large range of sizes in the low-carbon bars gives an opportunity for size with uniformity. Plates 2 and 6 of the 1913 tests show little difference between the 3/8-in. and the 1-in.bars; of the 1909 tests, Plates 3, 4, and 5 show the same result; it is evident, therefore, that size has little to do with the uniformity.

It is not necessary for reinforcing material to be absolutely uniform because the load on a particularly weak bar will be transferred by the concrete to the stronger ones. It is desirable to have nearly all the bars within a given range. The number of bars of each variety lying within ranges of 20, 25, and 30 per centbetween maximum and minimum values is shown in Table I. This table shows that there is a large difference in uniformity between low-carbon and high-carbon bars, and

little difference between high-carbon new billet steel and high-carbon rail steel.

IV. CONCLUSIONS.

Any conclusions drawn from a small number of tests will not be trustworthy. The term uniformity itself suggests large numbers, and tests for the study of the uniformity of a material should have a very wide scope before authoritative generalizations can be drawn. Of the bars tested, however, the following statements may be made:

The yield point is the least variable and the elongation the most variable of the three properties.

A wide variation in one property is accompanied by correspondingly wide variations in the other two properties.

Size has little effect on uniformity.

High-carbon steel is much more variable than low-carbon, therefore a larger factor of safety should be used with it.

Rail steel differs little from high-carbon new billet steel in uniformity.

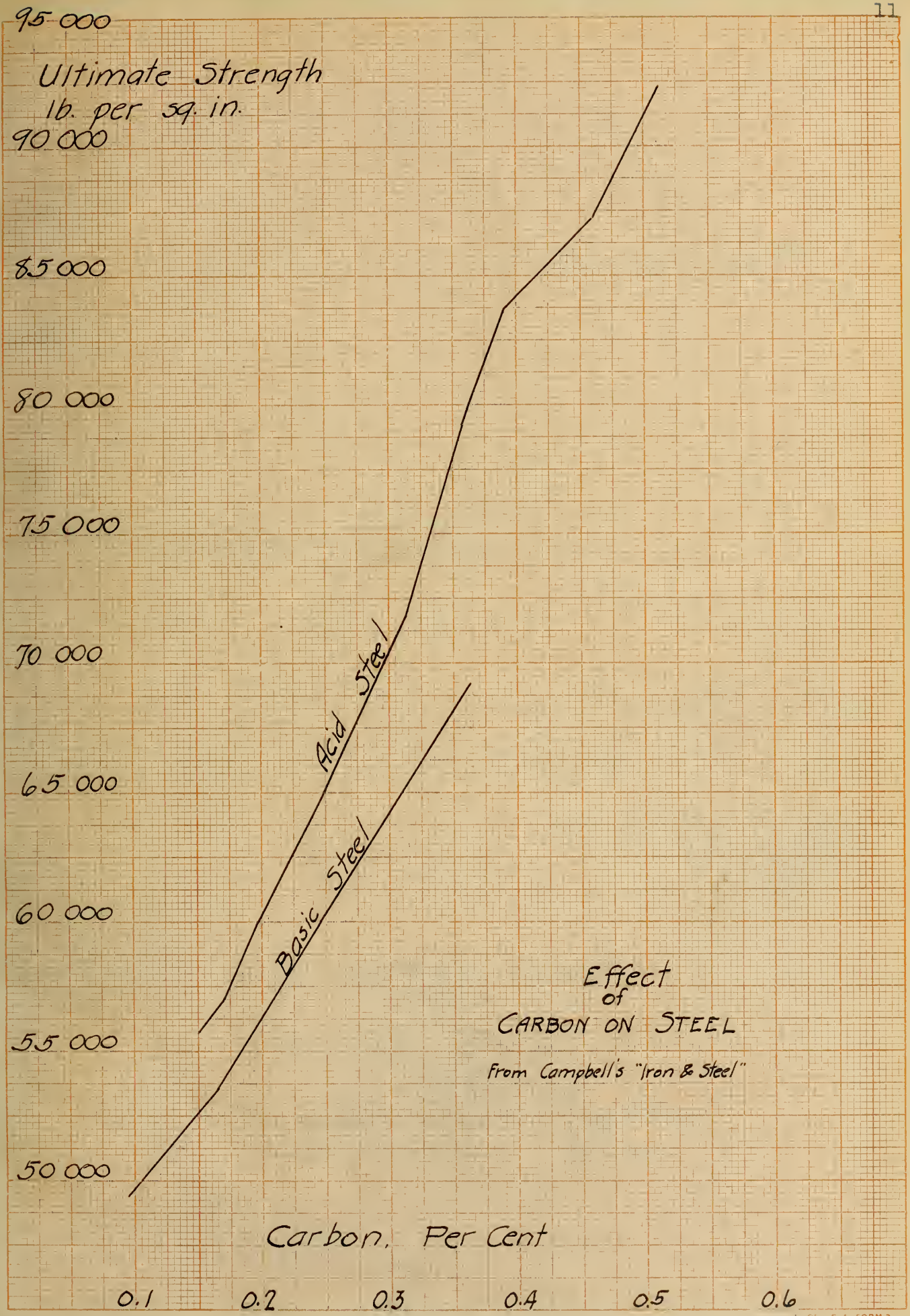

95 000
Ultimate Strength
lb. per sq. in.
90 000
85 000
80 000
75 000
70 000
65 000
60 000
55 000
50 000
Acid Steel
Basic Steel
Effect
of
CARBON ON STEEL
From Campbell's "Iron & Steel"
Carbon, Per Cent
0.1
0.2
0.3
0.4
0.5
0.6

PLATE 1

Per Cent of Mean

125

120 — Ultimate = 70 000 #/□"

115

110

105

MEAN

95

90

85 — Ultimate = 50 000 #/□"

Y.P. = 33 000 #/□"

80

Mean Yield Point = 40 420 #/□"
" Ultimate = 58 090 #/□"
" Elongation = 38.4 %

75

70

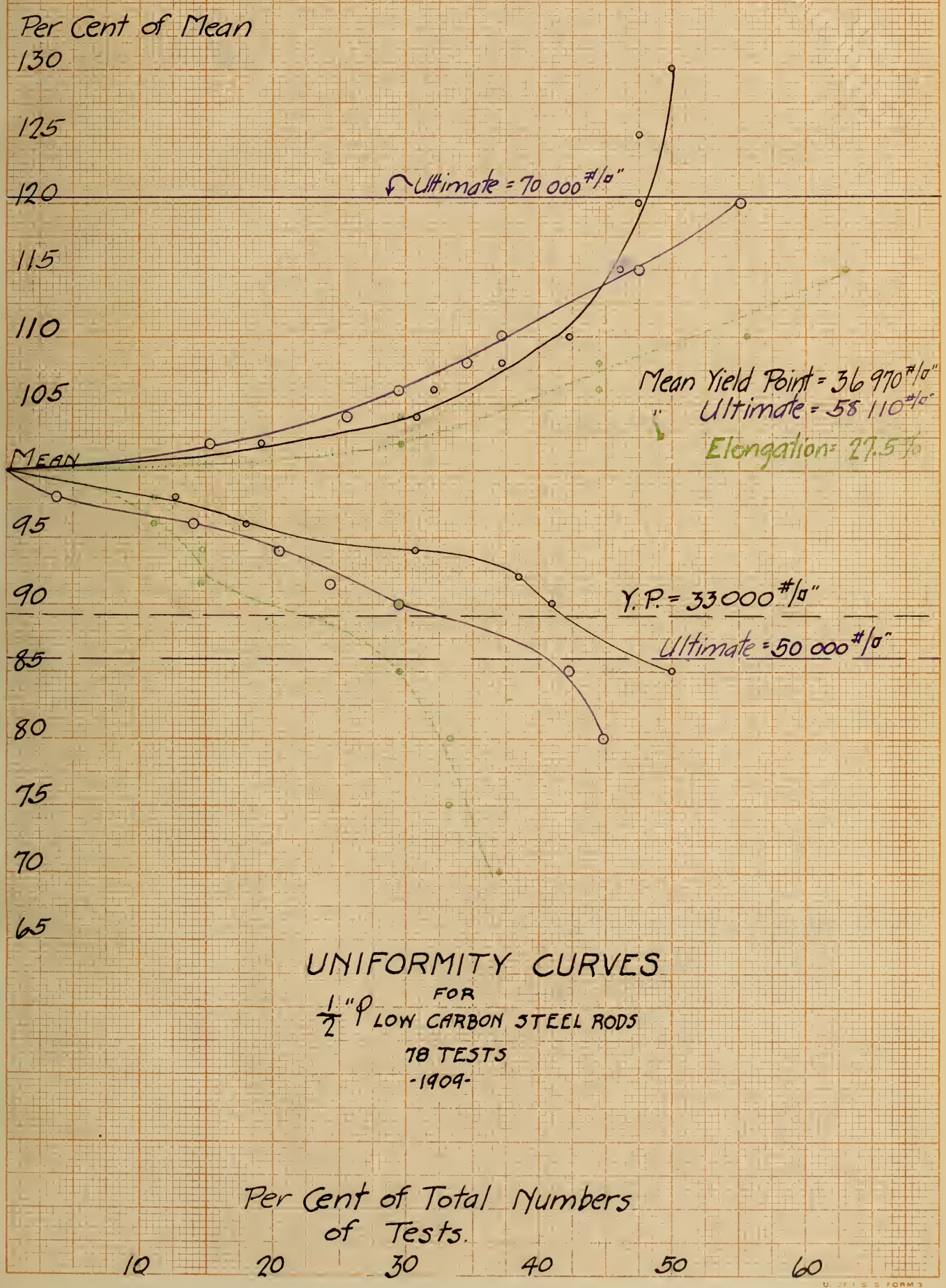
UNIFORMITY CURVES
SHOWING
PER CENT OF TOTAL NO. of TESTS
LYING BETWEEN THE
MEAN AND
ANY GIVEN PER CENT OF THE MEAN
$\frac{3}{8}$" ϕ LOW CARBON RODS 88 TESTS
TESTS MADE 1913.

Per Cent of Total Number of Tests.

10 20 30 40 50 60

U. OF I. S. S. FORM 3

PLATE 2



UNIFORMITY CURVES

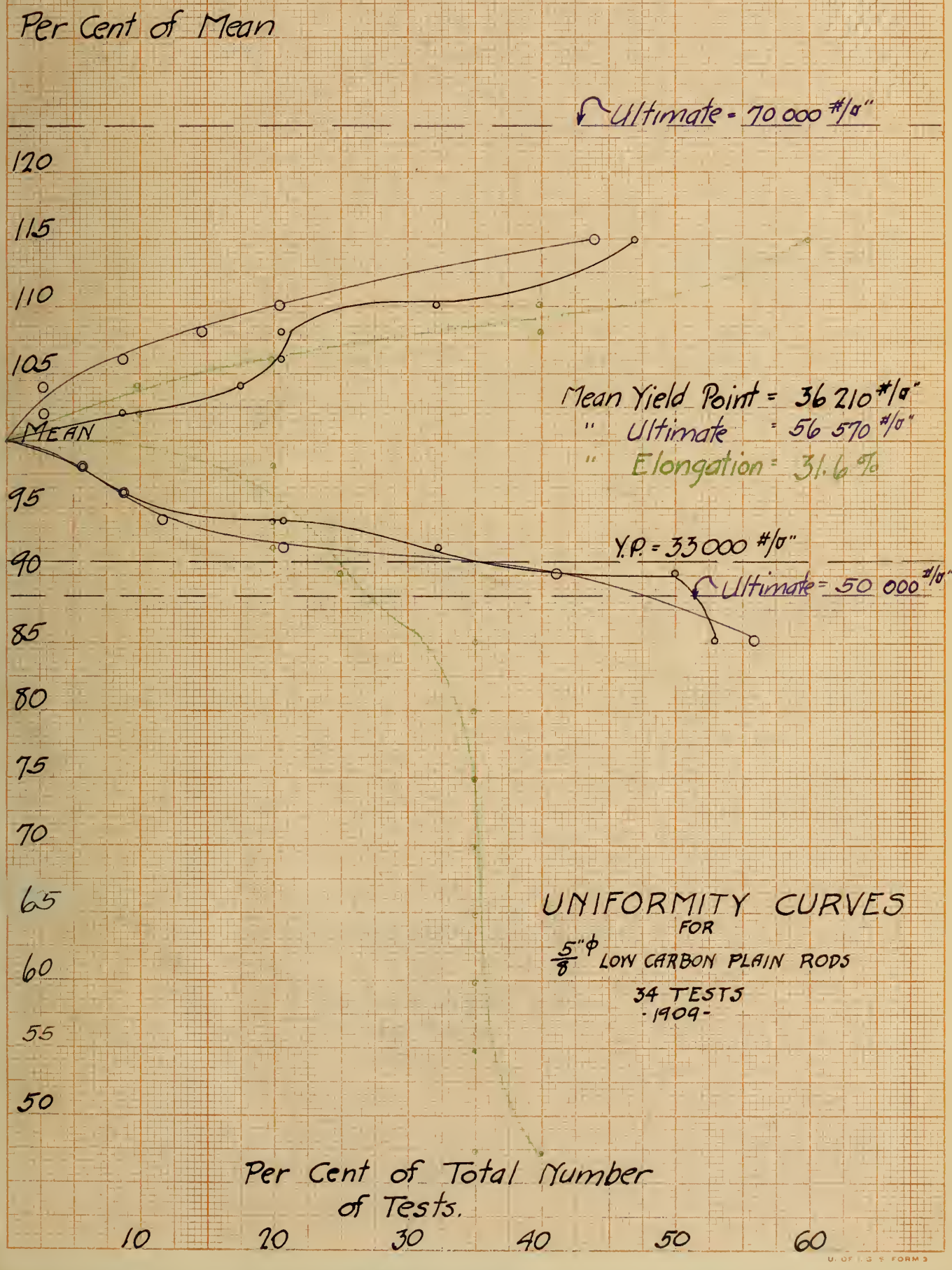
FOR

½" ϕ LOW CARBON STEEL RODS

78 TESTS

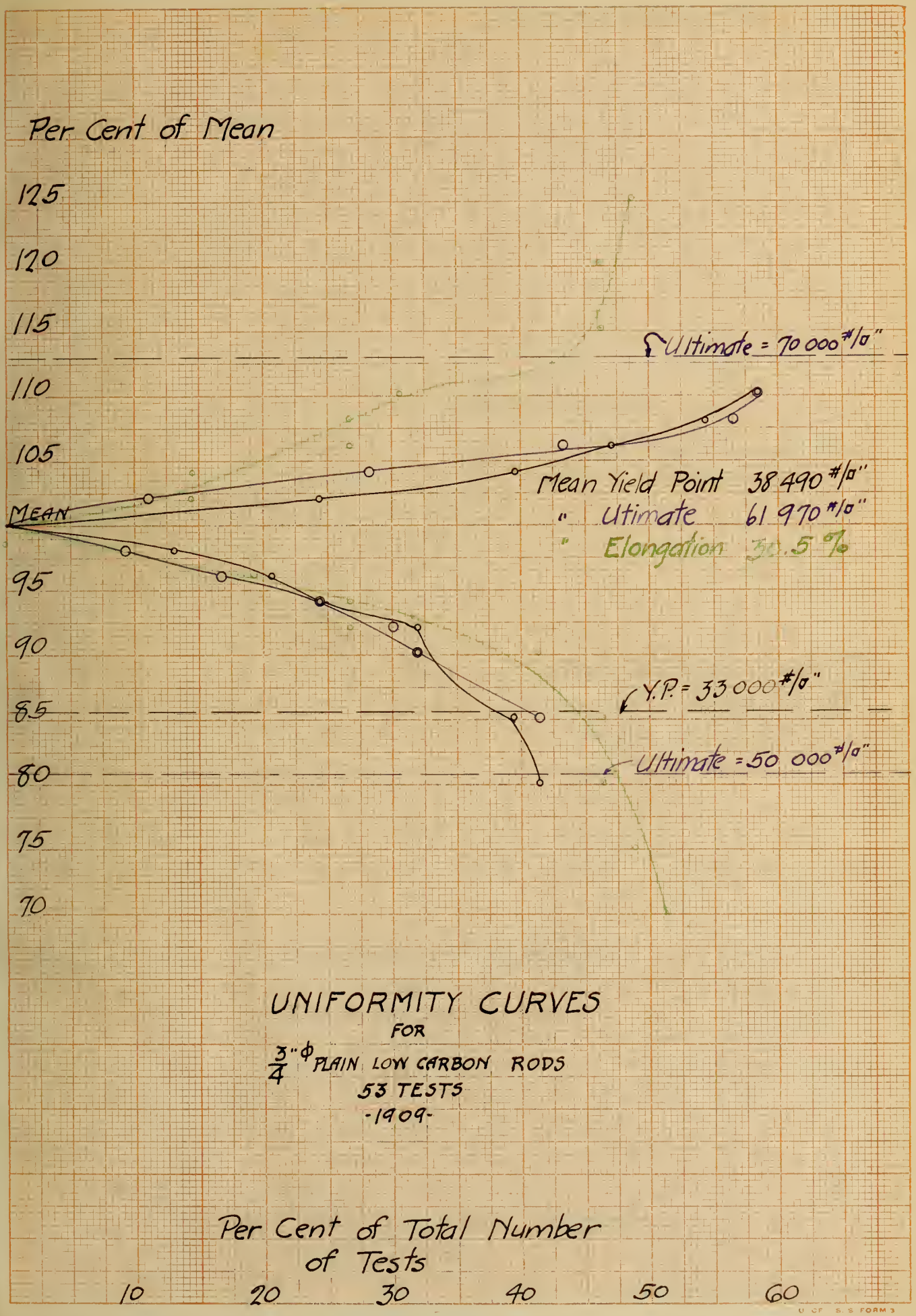
-1909-

PLATE 3



U. OF I. S. FORM 3

PLATE 4



UNIFORMITY CURVES

FOR

$\frac{3}{4}$" ϕ PLAIN LOW CARBON RODS

53 TESTS

-1909-

PLATE 5

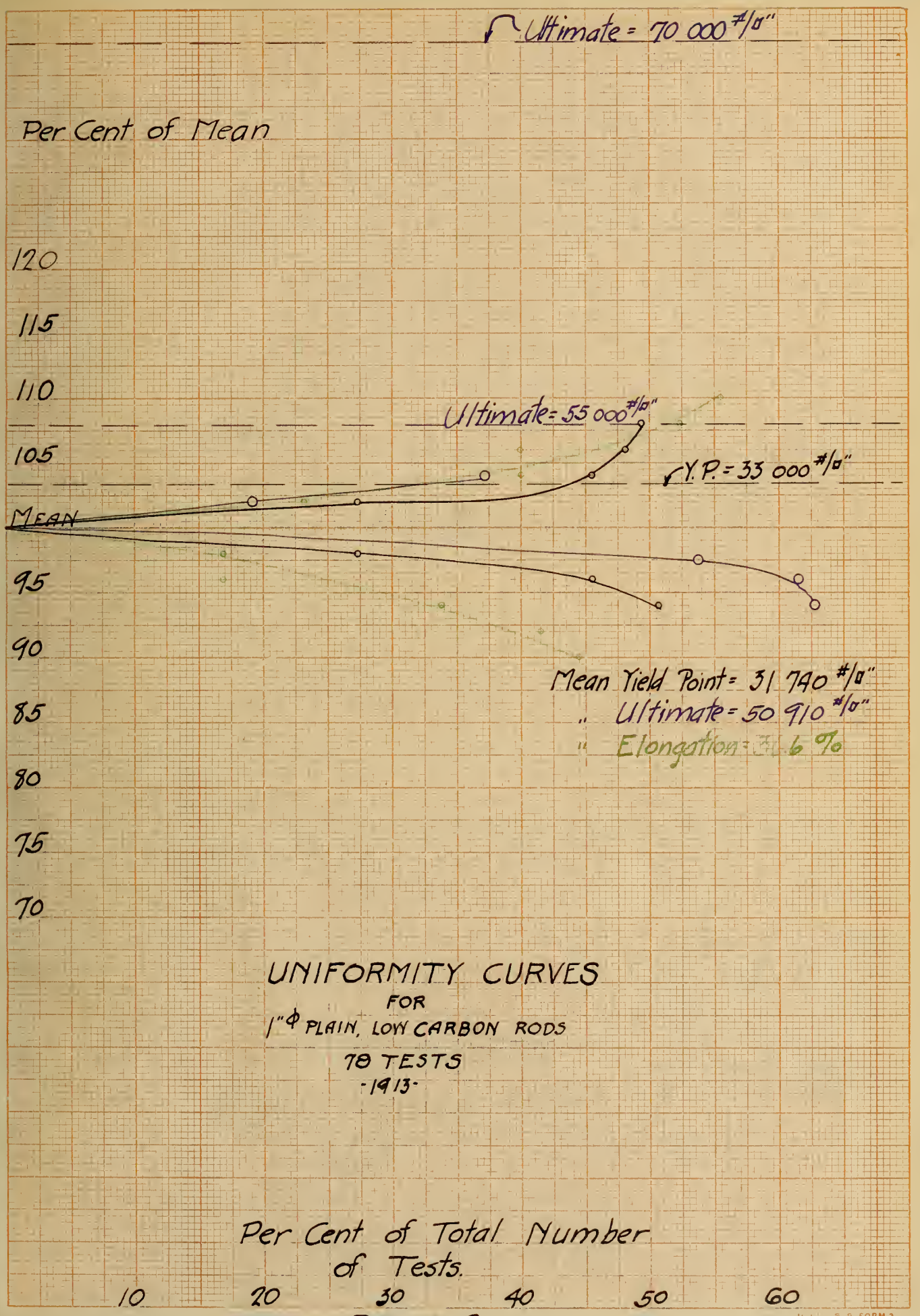
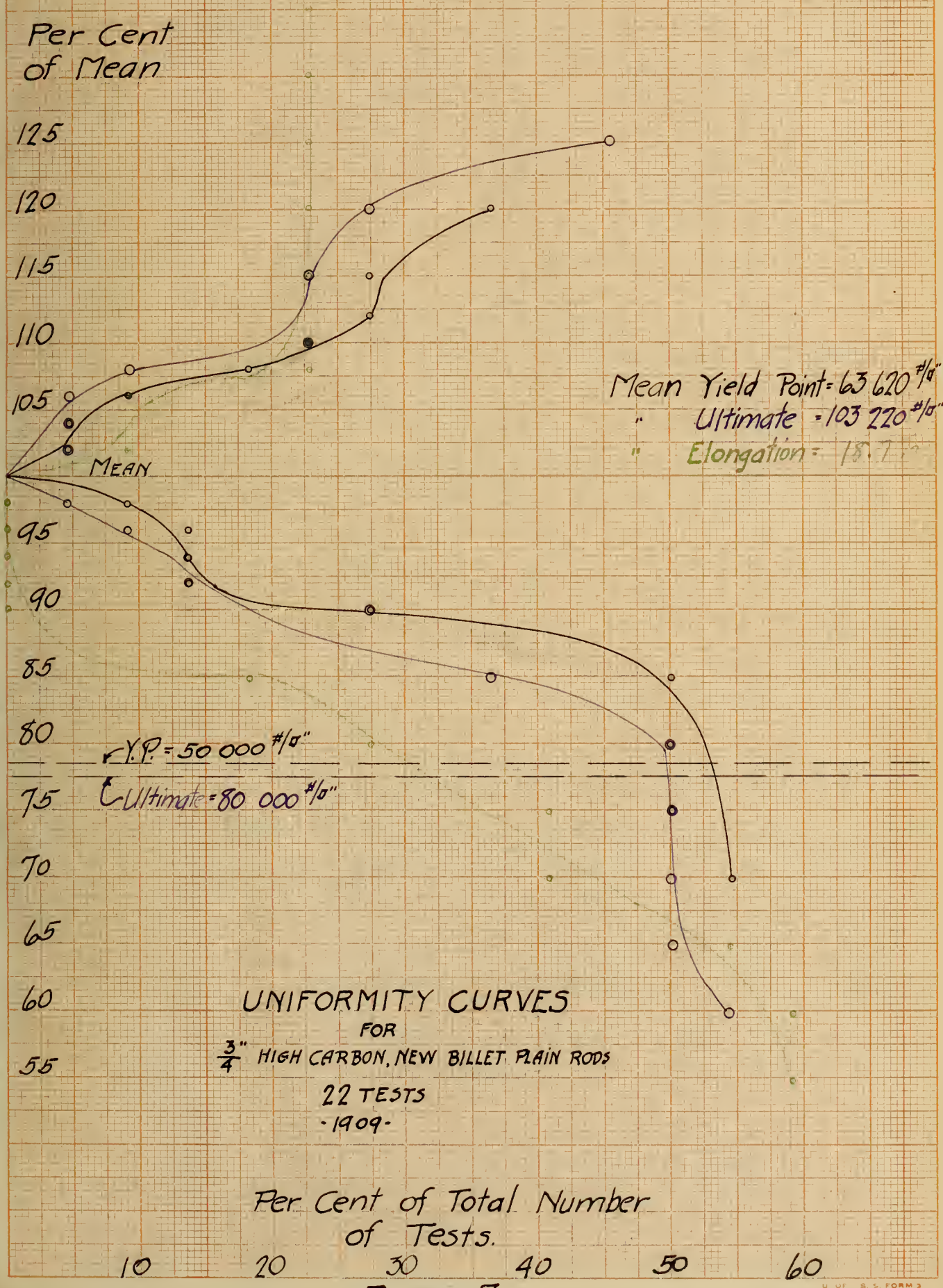
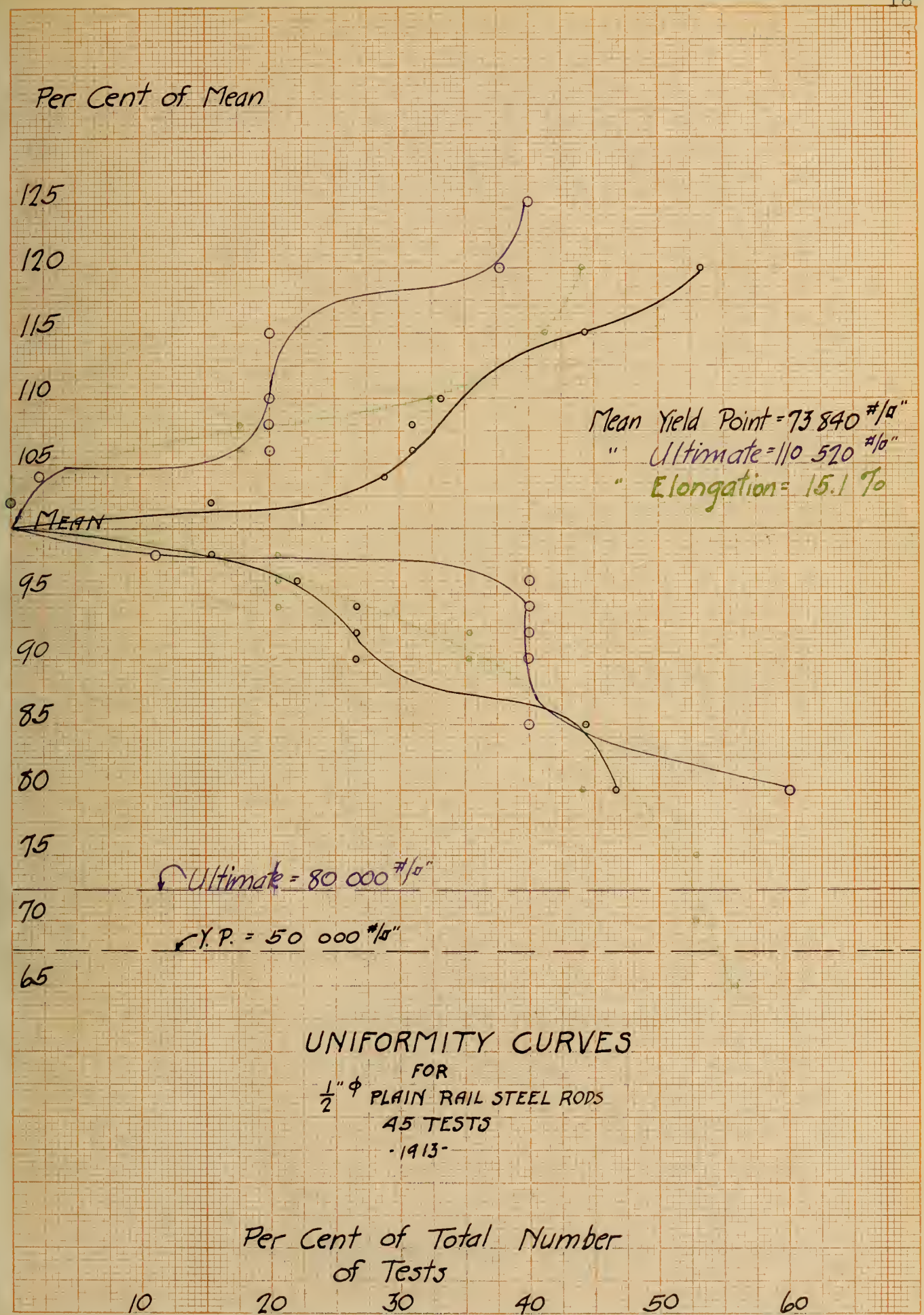

Ultimate = 70 000 #/□"
Per Cent of Mean
120
115
110
105
MEAN
95
90
85
80
75
70
Ultimate = 55 000 #/□"
Y.P. = 33 000 #/□"
Mean Yield Point = 31 740 #/□"
" Ultimate = 50 910 #/□"
" Elongation = 31.6 %
UNIFORMITY CURVES
FOR
1"Φ PLAIN, LOW CARBON RODS
78 TESTS
-1913-
Per Cent of Total Number
of Tests.
10
20
30
40
50
60

PLATE 6



UNIFORMITY CURVES
FOR
$\frac{3}{4}$" HIGH CARBON, NEW BILLET PLAIN RODS
22 TESTS
-1909-

PLATE 7



UNIFORMITY CURVES

FOR

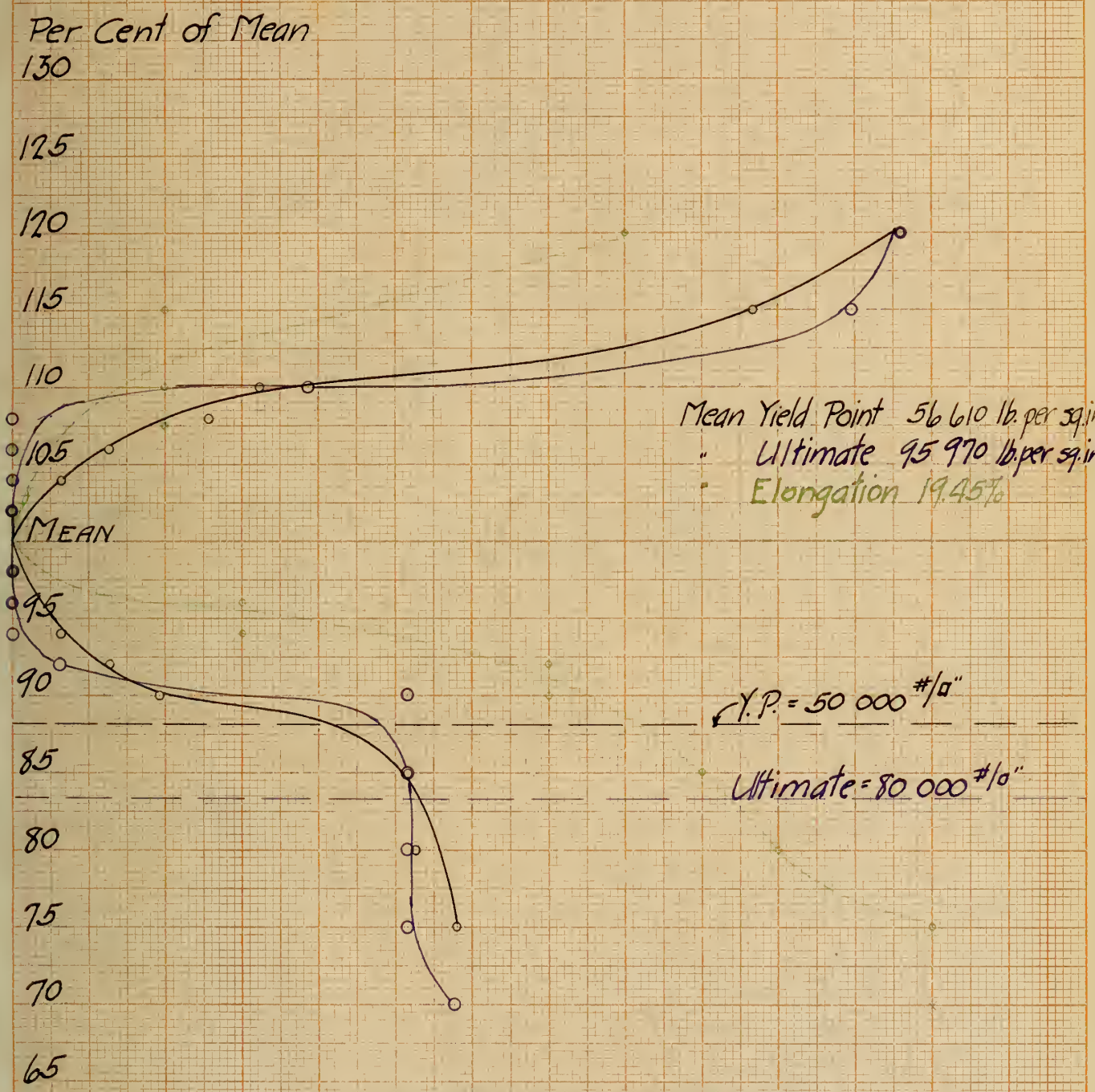
$\frac{1}{2}$" ϕ PLAIN RAIL STEEL RODS

45 TESTS

-1913-

PLATE 8

U. C. I. S. S. FORM 3



UNIFORMITY CURVES
FOR
1" ϕ PLAIN RAIL STEEL RODS
31 TESTS
-1913-

Per Cent of Total Number of Tests.

10 20 30 40 50 60

PLATE 9

U. OF S. S. FORM 3

TABLE I.

PER CENT OF TESTS LYING WITHIN GIVEN RANGE OF EXTREME VALUES.

	20 Per Cent			25 Per Cent			30 Per Cent		
	Y.P.	Ult.	Elong.	Y.P.	Ult.	El.	Y.P.	Ult.	El.
3/8-in. low-carbon	100	100	95	100	100	100	100	100	100
1/2-in. " "	83	70	72	92	80	84	95	89	93
5/8-in. " "	82	62	81	97	85	86	100	100	91
3/4-in. " "	90	92	76	98	100	85	100	100	91
1-in. " "	100	100	100	100	100	100	100	100	100
3/4-in. hard, billet	61	55	33	73	59	48	79	73	55
1/2-in. rerolled	74	62	69	78	75	79	88	80	83
1-in. "	58	58	50	68	70	63	76	83	78

TABLE II.

TENSION TESTS OF 3/8-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit loads Yield Pt.	Unit loads Ultimate
1a	.376	.1110	4 550	6 500	28	41 000	48 600
1b	.375	.1104	4 500	6 500	30	40 700	58 900
1c	.373	.1093	4 450	6 470	28	40 700	59 100
1d	.374	.1099	4 490	6 500	28	40 800	59 100
1e	.373	.1093	4 510	6 500	29	41 300	59 400
1f	.372	.1087	4 440	6 550	28	40 800	60 300
1g	.376	.1110	4 510	6 550	27	40 700	59 000
1h	.373	.1093	4 550	6 510	28	41 600	59 500
1i	.376	.1110	4 570	6 570	30	41 200	58 300
1j	.375	.1104	4 540	6 540	27	41 000	59 100
1k	.375	.1104	4 500	6 510	26	40 700	59 000
2a	.377	.1116	4 520	6 550	28	40 600	58 800
2b	.376	.1110	4 460	6 570	27	40 200	59 200
2c	.378	.1122	4 550	6 510	31	40 600	58 000
2d	.377	.1116	4 470	6 540	29	40 000	58 600
2e	.377	.1116	4 500	6 510	30	40 400	58 400
2f	.377	.1116	4 560	6 570	29	41 000	59 000
2g	.378	.1122	4 560	6 510	29	40 600	58 000
2h	.377	.1116	4 540	6 560	27	40 700	58 900
2i	.378	.1122	4 400	6 530	27	39 200	58 200
2j	.379	.1128	4 530	6 520	29	40 100	57 800
2k	.376	.1110	4 430	6 440	28	39 900	58 000
3a	.377	.1116	4 570	6 570	29	41 000	59 000
3b	.376	.1110	4 420	6 460	25	39 800	58 200
3c	.378	.1122	4 480	6 450	29	39 900	57 500

TABLE II.

TENSION TESTS OF 3/8-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Ultimate	Elong. %	Unit Loads Yield Pt.	Ultimate
3d	.376	.1110	4 440	6 470	26	40 000	58 300
3e	.376	.1110	4 530	6 470	28	39 900	58 300
3f	.376	.1110	4 510	6 440	28	39 700	58 000
3g	.377	.1116	4 400	6 430	29	39 500	57 600
3h	.377	.1116	4 610	6 450	25	41 400	57 800
3i	.375	.1104	4 600	6 450	28	41 600	58 400
3j	.377	.1116	4 520	6 450	28	40 500	57 800
3k	.377	.1116	4 620	6 440	30	41 500	57 700
4a	.375	.1104	4 450	6 320	30	40 300	57 200
4b	.373	.1093	4 420	6 290	28	40 400	57 400
4c	.373	.1093	4 410	6 330	29	40 300	57 900
4d	.373	.1093	4 420	6 320	28	40 400	57 800
4e	.372	.1087	4 430	6 340	28	40 700	58 300
4f	.372	.1087	4 420	6 290	28	40 600	57 900
4g	.372	.1087	4 460	6 300	27	41 100	58 000
4h	.371	.1081	4 460	6 270	26	41 200	58 000
4i	.371	.1081	4 430	6 290	27	40 900	58 100
4j	.372	.1087	4 410	6 280	29	40 600	57 800
4k	.373	.1093	4 400	6 310	28	40 300	57 700
5a	.376	.1110	4 300	6 390	29	38 800	57 500
5b	.375	.1104	4 430	6 380	29	40 100	57 700
5c	.376	.1110	4 560	6 370	30	41 100	57 400
5d	.375	.1104	4 400	6 390	29	39 800	57 800
5e	.376	.1110	4 440	6 380	28	40 000	57 400
5f	.376	.1110	4 520	6 380	31	40 700	57 300

TABLE II.

TENSION TESTS OF 3/8-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
5g	.375	.1104	4 490	6 360	28	40 600	57 600
5h	.375	.1104	4 460	6 370	28	40 400	57 700
5i	.376	.1110	4 410	6 340	31	39 800	57 100
5j	.376	.1110	4 520	6 370	29	40 700	57 400
5k	.376	.1110	4 510	6 370	30	40 600	57 300
6a	.376	.1110	4 490	6 460	31	40 400	58 200
6b	.377	.1116	4 530	6 450	30	40 600	57 800
6c	.377	.1116	4 440	6 440	28	39 800	57 700
6d	.376	.1110	4 520	6 430	29	40 700	57 900
6e	.376	.1110	4 420	6 450	31	39 800	58 100
6f	.378	.1122	4 460	6 450	28	39 800	57 500
6g	.378	.1116	4 540	6 430	31	40 600	57 600
6h	.376	.1110	4 500	6 460	30	40 600	58 200
6i	.377	.1116	4 540	6 460	29	40 600	58 000
6j	.376	.1110	4 530	6 440	29	40 800	58 000
6k	.376	.1110	4 490	6 380	30	40 400	57 500
7a	.378	.1122	4 600	6 530	26	41 000	58 900
7b	.377	.1116	4 500	6 530	30	40 400	58 500
7c	.376	.1110	4 440	6 540	28	40 000	58 900
7d	.378	.1122	4 480	6 540	31	39 900	58 300
7e	.377	.1116	4 470	6 520	30	40 000	58 500
7f	.379	.1128	4 640	6 600	25	41 100	58 500
7g	.377	.1116	4 460	6 510	27	40 000	58 400
7h	.378	.1122	4 540	6 500	28	40 500	58 000
7i	.376	.1110	4 450	6 520	29	40 100	58 800

TABLE II.

TENSION TESTS OF 3/8-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Ultimate	Elong. %	Unit Loads Yield Pt.	Ultimate
7j	.376	.1110	4 530	6 530	29	40 800	58 900
7k	.375	.1104	4 510	6 500	29	40 900	58 900
8a	.376	.1110	4 420	6 380	26	39 800	57 600
8b	.376	.1110	4 500	6 370	29	40 600	57 400
8c	.377	.1116	4 360	6 360	29	39 200	57 000
8d	.377	.1116	4 400	6 370	29	39 500	57 100
8e	.376	.1110	4 400	6 380	26	39 600	57 500
8f	.375	.1104	4 450	6 370	27	40 300	57 600
8g	.376	.1110	4 380	6 370	27	39 400	57 400
8h	.377	.1116	4 460	6 350	28	40 000	57 000
8i	.374	.1099	4 460	6 370	28	40 600	58 000
8j	.376	.1110	4 500	6 400	29	40 600	57 600
8k	.376	.1110	4 490	6 350	29	40 500	57 200

TABLE III.

TENSION TESTS OF 1/2-IN. LOW-CARBON BARS - 1909.

Diameter inches	Elongation per cent	Unit Loads lb.per sq.in. Yield Point	Ultimate
.506	25	38 300	59 300
.508	30	35 600	56 800
.507	27	35 700	57 000
.508	30	37 500	56 400
.506	29	37 800	58 300
.508	27	37 000	58 400
.507	25	38 700	61 000
.506	28	37 800	58 300
.506	28	35 800	58 300
.505	26	37 400	59 400
.507	28	36 700	58 000
.505	28	37 400	56 900
.507	31	36 700	56 500
.506	25	35 800	56 800
.500	28	37 200	59 700
.507	20	35 700	56 500
.505	25	39 400	60 000
.508	28	37 500	58 900
.506	29	34 800	55 200
.502	27	33 800	56 100
.500	29	34 700	55 100
.498	23	35 000	56 600
.500	28	37 700	61 700
.501	28	37 000	57 200
.503	30	37 700	59 900

TABLE III.

TENSION TESTS OF 1/2-IN. LOW-CARBON BARS - 1909.

Diameter inches	Elongation per cent	Unit Loads - lb.per sq.in. Yield Point	Ultimate
.501	31	37 500	57 200
.499	29	37 300	58 800
.492		47 400	67 100
.498		44 000	65 500
.495		47 200	66 800
.498		40 300	60 200
.498		40 500	60 500
.500		40 800	58 500
.496		40 100	59 200
.500		38 300	58 200
.499		38 000	58 200
.495		37 900	58 300
.497		40 100	59 800
.495		39 300	60 400
.498		39 900	59 100
.507		34 700	50 300
.502		38 300	50 300
.500		36 700	55 600
.505		35 200	55 000
.508		41 500	61 300
.507		40 700	54 600
.500		36 600	64 500
.486		33 200	54 600
.500		35 000	64 000
.500		37 500	67 000

TABLE III.

TENSION TEST OF 1/2-IN. LOW-CARBON BARS - 1909.

Diameter inches	Unit Loads - lb. per sq. in. Yield Point	Ultimate
.490	33 500	52 200
.494	34 600	62 300
.505	36 300	65 700
.500	35 100	51 400
.500	37 000	52 200
.500	34 900	52 400
.500	34 400	51 000
.500	32 600	47 800
.500	36 400	52 300
.500	34 600	52 200
.502	39 800	67 700
.503	36 800	62 800
.500	32 800	53 000
.500	33 000	50 600
.500	36 400	64 100
.482	35 300	55 000
.500	34 200	62 000
.490	37 200	69 200
.495	36 500	61 800
.498	36 500	63 800
.490	38 000	68 700
.500	35 400	53 800
.500	32 100	47 200
.500	31 900	51 800
.495	37 400	65 500

TABLE IV.

TENSION TESTS OF 5/8-IN. LOW-CARBON BARS - 1909.

Diameter inches	Elongation per cent	Unit Loads - lb.per sq.in. Yield Point	Ultimate
.631	31	33 600	52 200
.625	29	35 900	60 700
.628	34	32 300	50 700
.623	31	36 400	61 300
.624	31	34 700	52 300
.628	35	34 300	51 400
.627	35	34 000	50 900
.622	32	36 700	62 000
.625	34	33 300	50 900
.628	33	33 600	51 400
.619	15	38 200	60 500
.633	32	34 300	52 500
.629	34	34 800	54 100
.625	36	32 900	48 900
.623	31	33 500	51 200
.629	33	32 900	50 900
.627	36	33 100	51 600
.625	34	33 300	51 900
.619	28	33 200	51 800
.627	28	34 300	51 800

TABLE IV.

TENSION TESTS OF 5/8-IN. LOW-CARBON BARS - 1909.

Diameter inches	Unit Loads - lb. per sq. in. Yield Point	Ultimate
.620	35 500	55 500
.617	36 300	56 300
.615	41 400	59 700
.620	40 100	54 900
.622	40 600	64 800
.623	39 800	64 300
.622	39 200	62 600
.622	39 800	62 700
.621	39 500	62 000
.619	41 600	64 500
.620	40 600	54 400
.625	37 200	59 800
.617	37 200	57 100
.621	37 100	54 600

TABLE V.

TENSION TESTS OF 3/4-IN. LOW-CARBON BARS - 1909.

Diameter inches	Elongation per cent	Unit Loads-lb.per sq.in. Yield Point	Ultimate
.750	30	39 000	63 400
.750	32	36 900	57 700
.755	31	41 200	66 700
.747	33	39 300	61 000
.750	29	43 000	66 300
.750	31	38 000	62 500
.750	31	39 400	65 200
.753	28	41 300	66 000
.747	31	38 300	63 400
.752	30	37 800	62 300
.750	35	36 200	56 600
.751	35	36 100	57 400
.750	30	40 300	63 800
.755	30	37 200	59 300
.755	31	39 400	58 700
.748	32	38 200	60 800
.750	31	37 400	59 800
.748	26	39 000	62 600
.750	28	40 100	65 700
.752	30	38 300	64 200
.748	34	38 000	61 500
.749	34	34 500	55 700
.752	28	39 600	65 700
.746	30	39 900	64 600
.750	29	40 300	64 700

TABLE V.

TENSION TESTS OF 3/4-IN. LOW-CARBON BARS - 1909.

Diameter inches	Elongation per cent	Unit Loads lb.per sq.in, Yield Point	Ultimate
.752	29	39 200	63 000
.745	27	38 600	63 700
.747	22	37 200	61 800
.750	34	36 000	59 100
.750	28	35 500	59 100
.745	32	37 700	57 500
.748	32	41 000	63 300
.746	28	42 000	66 500
.750	35	40 300	59 600
.751	32	39 300	62 800
.744	23	41 900	66 600
.748	37	39 700	63 600
.752	30	38 500	60 300
.742	33	39 000	63 300
.745	30	41 200	66 200
.744	28	38 700	59 500
.744		34 400	53 800
.744		34 500	54 400
.746		33 900	54 500
.747		32 100	54 200
.746		38 800	61 800
.750		38 600	64 400
.751		38 800	65 400
.750		38 900	64 700
.751		38 200	64 700

TABLE VI.

TENSION TESTS OF 1-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
1a	0.99[illegible]	.774	24 900	39 800	39	32 200	51 400
1b	1.001	.787	25 000	39 800	37	31 800	50 500
1c	0.998	.782	24 900	39 600	38	31 800	50 600
2a	1.001	.787	25 500	39 500	37	32 400	50 100
2b	1.001	.787	25 100	39 400	36	31 900	50 000
2c	1.001	.787	24 600	39 500	37	31 200	50 100
3a	0.998	.782	25 200	39 900	36	32 200	51 000
3b	1.001	.787	24 700	40 000	36	31 400	50 800
3c	1.000	.785	24 800	39 800	36	31 600	50 700
4a	0.999	.784	25 300	40 600	38	32 300	51 900
4b	0.997	.781	25 600	40 600	34	32 800	52 000
4c	0.998	.782	24 800	40 200	33	31 700	51 500
5a	0.999	.784	24 100	39 500	37	30 800	50 500
5b	0.998	.782	25 800	39 300	34	33 000	50 200
5c	1.000	.785	24 200	39 900	39	30 800	50 800
6a	1.001	.787	24 300	39 700	36	30 900	50 500
6b	1.001	.787	24 500	39 700	39	31 100	50 500
6c	0.999	.784	24 300	39 600	39	31 000	50 600
7a	0.996	.779	24 400	39 200	36	31 300	50 400
7b	0.998	.782	23 800	39 300	37	30 400	50 200
7c	0.992	.773	23 900	39 300	38	30 900	50 900
8a	0.999	.784	24 000	39 700	39	30 600	50 600
8b	1.001	.787	24 200	39 600	-	30 700	50 400
8c	0.998	.782	23 900	39 800	39	30 600	50 800
9a	0.998	.782	25 800	39 700	35	33 000	50 700

TABLE VI.

TENSION TESTS OF 1-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
9b	0.997	.781	24 200	39 500	37	31 000	50 500
9c	0.997	.781	24 000	39 500	39	3o 700	50 500
10a	1.000	.785	24 500	39 100	38	31 200	49 800
10b	1.003	.790	23 800	39 000	-	30 100	49 400
10c	1.002	.789	23 700	39 000	40	30 100	49 500
11a	1.000	.785	26 800	41 200	37	34 100	52 500
11b	1.002	.789	25 600	41 100	37	32 500	52 100
11c	1.000	.785	25 400	41 300	36	32 400	52 600
12a	0.999	.784	24 700	39 600	37	31 500	50 600
12b	1.000	.785	24 300	39 500	40	32 200	52 300
12c	1.001	.787	24 500	39 500	35	31 100	50 100
13a	1.002	.789	24 400	39 700	36	30 900	50 300
13b	1.002	.789	24 600	39 600	37	31 200	50 200
13c	1.001	.787	24 600	39 100	36	31 200	49 600
14a	1.000	.785	24 800	39 600	38	31 600	50 400
14b	1.003	.790	24 800	39 700	35	31 400	50 200
14c	0.998	.782	24 500	39 500	37	31 300	50 500
15a	1.001	.787	25 400	39 900	35	32 200	50 600
15b	1.001	.787	24 700	39 800	37	32 400	50 500
15c	1.000	.785	24 800	39 900	34	31 600	50 800
16a	0.996	.779	24 300	38 500	38	31 200	49 500
16b	1.001	.787	23 800	38 400	39	30 200	48 800
16c	0.996	.779	24 200	38 400	-	31 100	49 400
17a	1.000	.785	26 400	41 400	-	33 600	52 600
17b	1.000	.785	25 500	41 300	-	32 400	52 500

TABLE VI.

TENSION TESTS OF 1-IN. LOW-CARBON BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
17c	1.001	.787	25 500	41 300	-	32 400	52 500
18a	1.000	.785	24 800	40 300	-	31 600	51 300
18b	1.001	.787	24 700	40 400	-	31 400	51 300
18c	1.000	.785	24 700	40 300	-	31 400	51 300
19a	1.001	.787	25 900	40 000	38	32 900	50 800
19b	1.000	.785	25 600	39 700	37	32 600	50 500
19c	1.000	.785	24 800	39 700	36	31 600	50 500
20a	1.000	.785	25 000	40 600	38	31 800	51 800
20b	0.999	.784	25 600	40 800	35	32 700	52 000
20c	0.999	.784	25 700	40 800	37	32 800	52 000
21a	1.000	.785	25 900	41 000	34	33 000	52 200
21b	0.999	.784	26 000	41 100	35	33 200	52 500
21c	1.001	.787	25 900	41 200	35	32 900	52 400
22a	0.998	.782	25 000	40 000	38	32 000	51 100
22b	1.000	.785	25 300	40 000	38	32 200	50 900
22c	0.999	.784	25 000	40 100	35	31 900	51 800
23a	1.001	.787	25 800	40 800	37	32 800	51 800
23b	1.000	.785	25 800	41 400	35	32 900	52 600
23c	1.002	.788	26 000	41 300	-	33 000	52 400
24a	1.001	.787	25 200	40 100	35	32 000	51 000
24b	1.002	.788	25 000	39 900	36	31 700	50 700
24c	1.002	.788	25 000	40 000	34	31 700	50 700
25a	1.002	.788	26 000	40 300	33	33 000	51 100
25b	1.000	.785	25 500	40 200	36	32 500	51 700
25c	1.002	.788	25 500	40 400	38	32 400	51 200

TABLE VII.

TENSION TESTS OF 3/4-IN. HIGH-CARBON, NEW BILLET BARS-1909.

Diameter inches	Elongation per cent	Unit Loads-lb.per sq.in. Yield Point	Ultimate
.727	14	68 900	113 500
.728	16	68 400	111 000
.738	19	57 200	92 200
.739	21	56 800	85 00
.725	12	55 900	93 800
.725	13	76 700	128 700
.730	13	76 200	127 100
.732	14	68 000	113 900
.740	21	60 400	9[illegible] 400
.734	15	57 800	88 800
.730	20	58 500	94 800
.725	10	77 200	128 700
.726	15	57 500	90 200
.732	1[illegible]	75 400	127 000
.725	14	70 400	120 000
.737	16	56 000	86 900
.731	15	67 100	112 000
.734	19	62 200	98 000
.738	16	63 800	104 000
.731	16	62 700	102 000
.737	14	55 300	87 300
.741	20	58 100	93 500

TABLE VIII.

TENSION TESTS OF 1/2-IN. RAIL STEEL BARS -1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
1a	.484	.184	13 600	19 800	15	73 900	107 800
1b	.480	.181	13 500	19 600	14	7[illegible] 500	108 100
1c	.482	.183	13 700	19 700	-	75 100	108 000
1d	.485	.185	13 600	19 700	16	73 600	106 800
1e	.484	.184	14 000	19 600	16	76 100	106 800
1f	.482	.183	14 000	19 700	16	76 700	108 000
1g	.482	.183	14 100	19 600	15	77 200	107 400
1h	.480	.181	13 800	19 700	-	76 200	108 900
1i	.481	.182	13 700	19 800	15	75 400	109 000
2a	.485	.185	13 000	19 700	18	70 400	106 800
2b	.484	.184	13 400	20 100	17	72 900	109 200
2c	.486	.186	13 500	20 100	-	72 800	108 200
2d	.486	.186	13 300	19 900	-	71 700	107 200
2e	.483	.183	13 200	20 100	-	72 000	109 900
2f	.486	.186	13 100	20 000	15	70 600	107 700
2g	.485	.185	13 200	20 000	17	71 500	108 200
2h	.484	.184	13 500	19 800	15	73 500	107 800
2i	.485	.185	13 600	20 300	15	73 700	110 000
3a	.486	.186	15 300	24 500	10	82 500	132 000
3b	.485	.185	15 900	24 100	12	86 100	130 500
3c	.483	.183	15 700	24 600	-	85 700	134 100
3d	.483	.183	15 900	24 300	-	86 900	132 100
3e	.487	.186	15 700	24 300	12	84 300	130 400
3f	.485	.185	15 400	24 400	13	83 500	132 100
3g	.483	.183	15 900	24 100	13	86 100	130 500

TABLE VIII.

TENSION TESTS OF ½-IN. RAIL STEEL BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
3h	.485	.185	15 400	24 400	12	83 500	132 100
4a	.486	.186	14 100	21 600	16	76 100	116 300
4b	.486	.186	14 800	21 400	14	79 800	115 200
4c	.485	.185	15 000	21 400	14	81 300	116 000
4d	.486	.186	14 000	21 300	15	75 400	114 900
4e	.485	.185	13 700	21 300	-	74 200	115 300
4f	.486	.186	13 900	21 500	13	74 900	115 900
4g	.486	.186	13 600	21 400	14	73 300	115 300
4h	.485	.185	13 700	21 500	16	74 200	116 400
4i	.486	.186	13 700	21 400	14	73 900	115 300
5a	.484	.184	11 600	16 800	19	63 100	91 300
5b	.483	.183	11 400	17 000	-	62 200	92 800
5c	.480	.181	11 500	16 800	16	63 500	93 900
5d	.481	.182	11 800	17 000	-	64 900	93 600
5e	.480	.181	11 600	16 700	17	64 100	92 300
5f	.479	.180	11 500	16 600	18	63 800	92 100
5g	.483	.183	11 600	16 700	17	63 400	91 100
5h	.481	.182	11 500	17 000	17	63 300	93 600
5i	.480	.181	11 600	16 900	18	64 100	93 400

TABLE IX.

TENSION TESTS OF 1-IN. RAIL STEEL BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
1a	.994	.776	50 700	81 600	19	65 400	105 100
1b	.993	.774	49 500	81 400	18	64 000	105 000
1c	.993	.774	49 500	81 400	19	64 000	105 000
1d	.996	.779	50 100	82 300	17	64 400	105 700
1e	.995	.778	50 000	81 900	18	64 400	105 200
1f	.994	.776	49 900	81 800	18	64 300	105 200
1g	.996	.779	49 700	82 400	17	63 900	105 800
1h	.995	.778	49 900	81 800	19	64 200	105 100
2a	.986	.764	41 400	67 200	23	54 100	88 000
2b	.988	.767	39 300	66 900	-	51 300	87 200
2c	.990	.770	40 200	67 600	23	52 200	87 900
2d	.986	.764	38 300	66 800	23	50 200	87 500
2e	.986	.764	38 500	67 100	21	50 500	87 900
2f	.986	.764	38 500	67 000	23	50 500	87 800
2g	.988	.767	38 600	67 700	2.	50 400	88 300
2h	.987	.765	38 700	67 500	-	50 500	88 200
3a	.993	.774	46 700	83 000	-	60 400	107 200
3b	.995	.778	51 100	82 400	-	65 800	106 000
3c	.993	.774	49 600	82 300	18	64 100	106 200
3d	.994	.776	49 400	82 100	-	63 600	105 900
3e	.997	.781	51 400	83 300	15	65 800	106 800
4a	.982	.757	44 100	81 900	15	58 300	108 000
4b	.981	.756	45 700	82 400	16	60 500	109 000
4c	.981	.756	46 800	82 500	-	61 900	109 100

TABLE IX.

TENSION TESTS OF 1-IN. RAIL STEEL BARS - 1913.

No.	Diam. in.	Area sq.in.	Loads-lb. Yield Pt.	Loads-lb. Ultimate	Elong. %	Unit Loads Yield Pt.	Unit Loads Ultimate
4d	.981	.765	45 300	83 500	-	60 000	110 500
4e	.982	.757	47 200	83 000	-	62 400	109 600
5a	.983	.759	31 300	53 200	-	41 300	70 200
5b	.981	.756	31 700	53 300	23	42 000	70 500
5c	.981	.756	31 000	52 900	-	41 000	70 000
5d	.981	.756	31 000	53 400	21	41 000	70 600
5e	.986	.764	32 500	53 800	-	42 600	70 500

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